

Pacific Islands Vulnerability Assessment

Coastal Species Narrative

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The Pacific Islands Fisheries Science Center conducted a climate change vulnerability assessment for six species groups in the Pacific Islands region (Giddens et al. unpublished). This data report summarizes the following assessments of each species in the coastal species group: overall climate vulnerability rank (certainty determined by bootstrap following [Hare et al. 2016](#)), climate exposure, biological sensitivity, distributional vulnerability rank, data quality, climate effects on abundance and distribution, and life history (see [Morrison et al. 2015](#) for further details).

Biological sensitivity and climate exposure were evaluated and scored by experts for each species. Biological sensitivity is representative of a species' capacity to respond to environmental changes in reference to a biological attribute. The Coastal Species Narrative is accompanied by the Coastal Species Profile, which provides further information on each biological sensitivity attribute for each species. The Coastal Species Profile was used to help experts evaluate biological sensitivity. Experts were also encouraged to use their own expertise and knowledge when evaluating. Climate exposure is defined as the degree to which a species may experience a detrimental change in a physical variable as result of climate change. The inclusion of climate exposure variables followed 4 guidelines: 1) the variables are deemed to be ecologically meaningful for the species and geography in question, 2) the variables should be available on the NOAA ESRL Climate Change Data Portal for consistency across different CVAs, 3) the variables are available in the temporal and spatial domains suitable for inclusion, and 4) the quality of the modeled product was judged to be adequate for inclusion. By following these guidelines, the exposure scoring was a quantitative exercise as future values could be compared to historical values while incorporating observed patterns of natural variability. This allowed determination of likely severity of future changes in exposure on a species- and area-specific basis for each exposure variable. Scoring for biological sensitivity and climate exposure is based on scale from 1–4 (Low, Moderate, High, Very High), and scoring for data quality is ranked from 0–3 (No Data, Expert Judgement, Limited Data, Adequate Data). A high score for biological sensitivity and climate exposure indicates greater

vulnerability. Expert Score Plots show the variation in expert scoring (5 experts per species). Scoring was completed in 2018. The mean score for each sensitivity attribute or exposure variable was calculated and a logic model was used to determine the component score for biological sensitivity and climate exposure. For example, if there are 3 or more attributes with a mean ≥ 3.5 , the sensitivity or exposure component score would be a 4 (Very High). Please see [Morrison et al. 2015](#) for remaining logic model’s criteria. Overall climate vulnerability was determined by multiplying sensitivity and exposure component scores; the possible range of these scores was between 1 and 16. The numerical values for the climate vulnerability rank were the following: 1–3 (Low), 4–6 (Moderate), 8–9 (High), and 12–16 (Very High).

Hare JA, Morrison WE, Nelson MW, Stachura MM, Teeters EJ, Griffis RB, Alexander MA, Scott JD, Alde L, Bell RJ, et al. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS One. 11: e0146756.

Morrison WE, Nelson MW, Howard JF, Teeters EJ, Hare JA, Griffis RB, Scott JD, Alexander MA. 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept. of Commer, NOAA. NOAA Technical Memorandum NMFS-OSF-3, 48 p.

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Bonefish - *Albula glossodonta*

Overall Vulnerability Rank = Moderate ■

Biological Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 89% of scores ≥ 2

<i>Albula glossodonta</i>		Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	2.4	2.8	
	Prey Specificity	1.6	2.6	
	Adult Mobility	2.2	2.6	
	Dispersal of Early Life Stages	1.6	2.4	
	Early Life History Survival and Settlement Requirements	2	1.2	
	Complexity in Reproductive Strategy	2	1.8	
	Spawning Cycle	1.5	2.4	
	Sensitivity to Temperature	1.2	2.8	
	Sensitivity to Ocean Acidification	2	2.2	
	Population Growth Rate	2	2.2	
	Stock Size/Status	2.5	1.6	
	Other Stressors	2.2	2.2	
	Sensitivity Score		Low	
Exposure variables	Bottom Salinity	1.6	3	
	Bottom Temperature	2.5	3	
	Current EW	1.2	3	
	Current NS	1.2	3	
	Current Speed	1.1	3	
	Mixed Layer Depth	1	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	4	3	
	Surface Chlorophyll	1.4	3	
	Surface Oxygen	4	3	
	Surface Salinity	1.5	3	
	Wind EW	1.1	3	
	Wind NS	1	3	
	Wind Speed	1	3	
	Exposure Score		Very High	
Overall Vulnerability Rank		Moderate		

Bonefish (*Albula glossodonta*)

Overall Climate Vulnerability Rank: **[Moderate]**. (96% certainty from bootstrap analysis).

Climate Exposure: **[Very High]**. Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[Low]**. No sensitivity attributes scored above a 3.0. The highest scores were for Habitat Specificity (2.4) and Stock Size/Status (2.5).

Distributional Vulnerability Rank: **[Moderate]**. Three attributes indicated moderate vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may mitigate the propensity of the species to shift distribution.

Data Quality: 89% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

This species occurs throughout 15 Spalding et al. [1] provinces in a variety of shallow, nearshore habitats over a wide range of latitudes, and appears to be relatively tolerant to changes in environmental conditions given its dispersive early life history stages and adult mobility. There are indications that the species could be sensitive to cold, based on field observations in Florida following an unusually cold event in 2010 [2] and laboratory experiments [3]. Tagging studies indicate movement potential between islands in the Hawaiian Archipelago [4]. The high degree of utilization of shallow, nearshore habitat makes this species vulnerable to climate impacts exacerbated or localized to such areas where effects may be further compounded by coastal development and watershed-based pollution. Close dependence on mangrove and seagrass areas by adults may further increase vulnerability of this species to climate effects as these areas continue to decline; additionally, metamorphosing post-larvae are known to recruit to estuarine areas, which are also high-risk areas for climate induced environmental change.

Life History Synopsis:

Albula glossodonta, the shortjaw or roundjaw bonefish, is one of two species of *Albula* occurring in the Pacific basin; the other is *A. virgata*, the sharpjaw bonefish. *A. glossodonta* occurs from Hawai'i and French Polynesia to the Seychelles in the western Indian Ocean, north to southern Japan and south to Lord Howe Island, Australia. It is found in 15 Spalding et al. [1] provinces from latitudes 32° N–32° S, and longitudes 42° E–139° W. *A. glossodonta* are found in a diversity of habitats such as shallow flats, sandy bottoms, seagrass beds, mangrove shorelines, reef and rubble, and other shallow coastal habitats. This species may be closely associated with mangroves and sea grasses in certain areas and are found from 0–50 m in depth. This species primarily feeds on crustaceans, polychaetes, and bivalves. It is moderately mobile as an adult and has a PLD of ~56 days. This species is known to form spawning aggregations which can become vulnerable targets for fishers, particularly gill-net fishers. In a Hawaiian study, the abundance of juvenile *A. glossodonta* was variable throughout the year with a peak in December and another from March through June. *Albula sp.* reared in the lab were sexually mature at 2–3 years of age [5]. Other studies have estimated growth for *A. glossodonta* at 0.4 cm per month [4], von Bertalanffy K at 0.18 [6], von Bertalanffy L-infinity at 67.26 cm, longevity at 14 years [6], and natural mortality rate at 0.046 [4]. This species is currently listed as Vulnerable by the IUCN.

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Mackerel scad - *Decapterus macarellus*

Overall Vulnerability Rank = Moderate ■

Biological Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 82% of scores ≥ 2

<i>Decapterus macarellus</i>		Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.2	3	
	Prey Specificity	1.1	2.8	
	Adult Mobility	1.6	3	
	Dispersal of Early Life Stages	1.1	1.9	
	Early Life History Survival and Settlement Requirements	1.8	1.6	
	Complexity in Reproductive Strategy	1.4	1.2	
	Spawning Cycle	1.6	2.8	
	Sensitivity to Temperature	1.1	2.6	
	Sensitivity to Ocean Acidification	1.7	2.4	
	Population Growth Rate	1.1	2.2	
	Stock Size/Status	1.3	1.8	
	Other Stressors	1.5	1.4	
	Sensitivity Score		Low	
Exposure variables	Bottom Salinity	2.1	3	
	Bottom Temperature	3.3	3	
	Current EW	1.3	3	
	Current NS	1.3	3	
	Current Speed	1.3	3	
	Mixed Layer Depth	1	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	4	3	
	Surface Chlorophyll	1.5	3	
	Surface Oxygen	3.9	3	
	Surface Salinity	1.6	3	
	Wind EW	1.1	3	
	Wind NS	1.1	3	
	Wind Speed	1.1	3	
	Exposure Score		Very High	
Overall Vulnerability Rank		Moderate		

Mackerel Scad (*Decapterus macarellus*)

Overall Climate Vulnerability Rank: **[Moderate]**. (100% certainty from bootstrap analysis).

Climate Exposure: **[Very High]**. Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[Low]**. No sensitivity attributes scored above a 3.0. The highest scores were for Early Life History and Settlement Requirements (1.8) and Sensitivity to Ocean Acidification (1.7).

Distributional Vulnerability Rank: **[Very High]**. Three attributes indicated very high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was low which may mitigate the propensity of the species to shift distribution.

Data Quality: 82% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

The mackerel scad, *Decapterus macarellus*, is extraordinarily widespread, found in all three oceans, on continental shelves, and on oceanic islands from the tropics to fairly high latitudes (Canada 50° N and South Africa 35° S). It has a depth range of 0–400 m, though more frequently occurring at 0–200 m. Juveniles in Hawai'i seen in large schools near the surface of offshore waters, while the larger individuals are often seen closer to shore [1]. As “nearshore pelagics,” scads may actually be among the relatively few species that benefit from future global changes, unlike open-ocean and coral-reef fishes, which are affected by stratification and nutrient-runoff, respectively.

Increased CO₂ in the atmosphere not only increases ocean temperature, lowers pH, and raises sea level, the increased CO₂ also causes ocean stratification via the increased sea surface temperature. As the ocean warms, the water becomes less dense and thereby remains on top, inhibiting mixing. With reduced mixing, there is less oxygen uptake from above [2], narrowing the acceptable habitat of some species of open-ocean fishes to nearer the surface [3], making them more vulnerable to fishing gear. Reduced mixing also leads to less nutrient input from below, which has resulted in a steady reduction in mid-ocean productivity since the late 1800s [4]. However, climate change may affect scads less than other open-ocean fishes because they tend to concentrate near the shore where there is substantially less, if any, stratification because of the mixing effects of water motion caused by interactions with land masses.

Like the bigeye scad, the mackerel scad actually may be among the relatively few species that benefit from future global changes by being nearshore and a part of a plankton-based trophic system. The worldwide average of soil erosion from agricultural land is 30 tonnes per hectare per year [5]. Sedimentation is harmful to benthic communities such as coral reefs, but nutrient-runoff can increase the phytoplankton which increases the zooplankton and is beneficial for the nearshore pelagics such as scads.

Life History Synopsis:

The mackerel scad is a relatively hardy species as evidenced by its wide distribution, generalized habitat and prey requirements, and by its ability to sustain populations under heavy exploitation. mackerel scad (called “opelu” in Hawai‘i) are important prey for larger predators as well as an important baitfish for commercial and recreational fishers. This species demonstrates impressive sustained productivity and turnover. WJ Walsh (unpublished data) examined 64 years (1949–2013) of catch records of opelu in a relatively heavily fished section on the southwest coast of the island of Hawaii. Although the catch per fisher has generally declined, the catches have been fairly stable and substantive in recent years. Opelu and akule have provided substantial catch that appears to have been sustained in the main Hawaiian Islands for over three decades of harvest [6]. Between 1948 and 2000 in the Philippines, there was a substantial decrease in catch per unit effort, yet the total annual catch of small nearshore pelagic fish such as scads stayed relatively constant¹, as was the catch of Decapterus². The rapid development to maturity (18 months), fast growth (asymptotic length at 2–3 years), generalized habitat and prey requirements, large population sizes over broad geographic and depth ranges, together indicate that mackerel scad is potentially resilient and not especially sensitive. These life-history traits of nearshore pelagics give the potential to sustain a fishery longer than is likely for open-ocean and coral-reef fishes. Even if overfished, small nearshore pelagics have the potential to recover in less than decades if local precautionary management is undertaken.

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¹ www.innri.unuftp.is/pdf/Philippine%20Fishries.pdf

² www.fao.org/fi/oldsite/FCP/en/phl/profile.htm

Pacific Islands Vulnerability Assessment – Coastal Species Narrative

Mullet - *Mugil cephalus*

Overall Vulnerability Rank = Moderate ■

Biological Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 96% of scores ≥ 2

<i>Mugil cephalus</i>		Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.9	3	
	Prey Specificity	1.6	2.8	
	Adult Mobility	1.9	2.8	
	Dispersal of Early Life Stages	1.6	2.4	
	Early Life History Survival and Settlement Requirements	1.9	1.8	
	Complexity in Reproductive Strategy	1.9	2.4	
	Spawning Cycle	1.8	2.6	
	Sensitivity to Temperature	1.5	3	
	Sensitivity to Ocean Acidification	1.7	2.4	
	Population Growth Rate	1.8	2	
	Stock Size/Status	1.4	2	
	Other Stressors	2.1	2.2	
	Sensitivity Score		Low	
Exposure variables	Bottom Salinity	2	3	
	Bottom Temperature	3.4	3	
	Current EW	1.3	3	
	Current NS	1.3	3	
	Current Speed	1.3	3	
	Mixed Layer Depth	1	3	
	Ocean Acidification	4	3	
	Precipitation	1.1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	4	3	
	Surface Chlorophyll	1.5	3	
	Surface Oxygen	3.8	3	
	Surface Salinity	1.6	3	
	Wind EW	1.1	3	
	Wind NS	1.1	3	
	Wind Speed	1.1	3	
	Exposure Score		Very High	
Overall Vulnerability Rank		Moderate		

Mullet (*Mugil cephalus*)

Overall Climate Vulnerability Rank: **[Moderate]**. (99% certainty from bootstrap analysis).

Climate Exposure: **[Very High]**. Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[Low]**. No sensitivity attributes scored above a 3.0. The highest scores were for Habitat Specificity (1.9), Adult Mobility (1.9), Early Life History and Settlement Requirements (1.9), and Complexity in Reproductive Strategy (1.9).

Distributional Vulnerability Rank: **[High]**. Three attributes indicated high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may mitigate the propensity of the species to shift distribution.

Data Quality: 96% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

The eurythermal and euryhaline tolerances (12-25 °C; 0–35 psu) of striped mullet, as well as a tolerance of low oxygen concentrations, reduce the striped mullet's vulnerability to many climate-change effects. The species exhibits shifts in range due to temperature changes [1,2], but adult mobility is usually not great. Striped mullet are not dependent on prey with calcareous shells or skeletons, which reduces the species vulnerability to ocean acidification. The species utilizes estuaries during its life cycle, particularly as nursery habitats. Those habitats are vulnerable to climate-change effects; however, adaptability by striped mullet to extremes in freshwater input by some populations indicates potential resiliency to those effects. Estuarine and other nearshore habitats used by the species are also vulnerable to coastal pollution. The species is vulnerable to red tide blooms, which may increase in some areas due to climate change. Some populations have been reduced by overfishing. Pollution, red tide blooms, and overfishing are therefore added stressors that may enhance climate-change vulnerability of the striped mullet.

Life History Synopsis:

The striped mullet (*Mugil cephalus*) is a circumglobally distributed species found from the tropics to warm temperate regions between 62° N–57° S, but primarily between 42° N–42° S, where water temperatures range from 8 °C–24 °C. The species occurs in 24 Spalding et al. [3] provinces. Some studies suggest that *Mugil cephalus* is now recognized as a group of allopatric cryptic species [4,5]. Although genetic differentiation between the populations approaches or exceeds that seen between species in other fish families, there is very little morphological variation among the populations. The species is considered to be an example of one in which the populations approach, but have not reached, differentiation into a group of cryptic species.

There is a huge amount of literature on this species because of its global importance to fisheries and aquaculture. The biology of this species was reviewed by Whitfield et al. [5] and Camera et al. [6]. Much of the information in this narrative comes from those reviews and they are not cited repetitiously herein. This species is pelagic, benthopelagic, and demersal in near-shore habitats, primarily at 0–20m, but rarely as deep as 120 m. Juveniles and adults are usually found in schools, and they can forage in

lagoons, estuaries, and lower courses of rivers, tolerating freshwater. Juveniles primarily occur in estuaries and lower courses of rivers. Striped mullet populations in locations with intermittent freshwater input can complete the life cycle in entirely marine waters, indicating adaptability in environmental requirements. Pre-juvenile and juvenile mullet are acclimatized to warmer temperatures and routinely choose shallow, warm waters in the intertidal zone. Recruiting juveniles of 10–30 mm TL occupy surf zones prior to entering estuaries, with most recruits being 15–25 mm TL. Juveniles also select shallow estuarine waters with temperature and salinity fluctuations [7,8]. Recruitment can be prolonged over several months. Adults can tolerate temperatures of 6–33 °C and salinities of 0–75 psu [5,6,9], although prolonged survival at salinities greater than 35 is suspect. The species also tolerates wide ranges of turbidity and oxygen concentrations with a number of physiological and behavioral adaptations. As body size increases, the preferred temperature range within a habitat tends to decrease with a preference of older juveniles and adults for reduced temperatures [7]. Evidence exists that the species can shift its range in response to climate change effects [1,2]. Mulletts exhibit an ontogenetic shift in their diet, feeding on zooplankton as juveniles and filtering algae, detritus, sediments, and small invertebrates as they become larger [5].

Striped mullet are mobile, moving between estuaries and coastal surface waters to spawn before returning to estuaries and freshwater. *M. cephalus* in the U.S. Gulf of Mexico do not make long migrations. Tag returns suggest they stay in a small region and after spawning, they return to their original bay [6,10].

Striped mullet are oviparous and gonochoristic, although some individuals exhibit non-functional hermaphroditic gonad characteristics. Their mating system is polyandrous. Sex ratios are generally 1:1. Fecundity and absolute fecundity range from 270,000–1.6 million eggs per individual per season and 2.9–16 million eggs, respectively. Reproduction takes place at various times of the year depending on the location. Decreasing water temperatures, passage of cold fronts, and falling barometric pressure may act as cues for spawning migrations [11,12]. In Australia, the presence of small juveniles (0.2-0.3 cm) indicates spawning occurs between March and September [8]. While in Hawaii, the reproductive season occurs from September to March. Additionally, *M. cephalus* in Florida reproduce between October and mid-January. In the northern Gulf of Mexico at temperatures between 23–25 °C, larvae are abundant from November and December [11,13].

Optimal temperature for embryonic development ranges from 21–25 °C, with diminished growth at temperatures above 26 °C [14-16]. However, Walsh et al. [17] found normal development at 20–30 °C and salinities of 15–36. The eggs and larvae are tolerant of oxygen levels as low as 5.0–5.4 g l⁻¹ [15]. 48 hours post fertilization, the eggs hatch and the larvae are approximately 2.4 mm long. Temperature and salinity tolerances increase during larval and juvenile development. The pelagic larval duration is not reported, but Whitfield et al. [5] stated that the young recruit to estuaries “after about a month at sea”. There is an extended pelagic pre-juvenile stage (the “querimana” stage) from about 10 mm to 18–28 mm SL [18]. Moving inshore to shallow water provides the larvae protection from predators as well as a feeding ground. Young mullet (5 cm) then move into slightly deeper waters [11,19,20]. Recruitment of fry (0.15–0.40 cm fork length) in South Africa occurred from July to October and to a lesser extent in May, June, and November. Settlement in many areas may be cued by increased coastal freshwater input, but the species also recruits to habitats with little or no freshwater inflow. Cooling temperatures have also been suggested as a recruitment cue [5].

Lizardfish, needlefish, crabs, sharks, dolphins, seals, birds, and other marine carnivores prey on *M. cephalus*. A wide variety of parasites and pathogens have been reported for striped mullet in both wild

and aquaculture populations [5]. Mullet are vulnerable to red tide organisms. Potentially as many as 16 different pathologies can be involved in cases of red tide-induced death in mullet [12].

There is large geographic variability in estimates of life history parameters for striped mullet, as expected for such a genetically variable species. The reliably reported maximum standard length for this species is 72 cm TL, although Thompson [21] reported a length of 120 cm. The lifespan of *M. cephalus* males in the Gulf of Mexico was estimated to be seven and eight years, respectively, with an average of five years [22]. However, Thompson [21] reported a maximum age of 16 years and Ibanez Aguirre et al. [23] estimated that it could be as great as 28.32 years. Maturity is reached at 2–3 years at about 30–50 cm, but usually occurs at three years and 30–39 cm [5,24]. Estimates of von Bertalanffy K are highly variable, from 0.099 to 0.96 [23,25-30]. The asymptotic maximum length (L_{∞}) has been estimated to be between 37.0–74.2 cm [23,25-30]. Estimates of total mortality rates per year range from 0.87 to 2.33 [27,29], of natural mortality from 0.33 to 1.173 [26,29,30], and fishing mortality from 0.344 to 0.54 [27,29]. Intrinsic rates of population increase (r) have not been reported.

This species is a common aquaculture species in several parts of the world. The practice goes back to at least the time of the Roman Empire in Europe and the development of fishponds by ancient Hawaiians, when wild juveniles were captured to be grown to harvestable sizes. Full life-cycle aquaculture, including for use in stock enhancement, was achieved in the late 20th century [31].

The striped mullet is a sought-after food fish in many regions, sold cultured as well as wild-caught, but most of the capture fisheries are small in scale. In some areas, young striped mullet are often caught for use as bait to catch larger, predatory species. The globally reported catch of striped mullet was about 170,000 tons in 2004 but declined to a little over 80,000 tons in 2007, increasing to about 110,000 tons in 2009 [5, fig. 10]. Striped mullet stocks in eastern Australia have been considered fished to capacity or overfished. Regions exhibiting declines in striped mullet catches include Taiwan [2], both coasts of Mexico, Cuba, the Adriatic Sea, and Egypt [5,6], but not islands of the Pacific. Fisheries management restrictions such as catch limits and closed seasons exist for *M. cephalus* in some regions (e.g., Mexico, the U.S. Gulf of Mexico, Hawai'i). This species occurs in a number of protected areas within its world-wide range. Aquaculture of striped mullet has replaced some of the diminished production of capture fisheries in some areas, but because much of that aquaculture depends on the collection of wild young for grow-out, it can affect the stocks of adult mullet available for capture fisheries. Mullet aquaculture also is practiced in areas that were previously parts of the natural, coastal fishing grounds, displacing the habitat and fisheries for wild fish. The striped mullet is rated as of Least Concern in the IUCN Red List of Threatened Species [6].

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Threadfin - *Polydactylus sexfilis*

Overall Vulnerability Rank = Moderate ■

Biological Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 75% of scores ≥ 2

<i>Polydactylus sexfilis</i>		Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)	
Sensitivity attributes	Habitat Specificity	1.9	2.4		<div style="display: flex; flex-direction: column; gap: 5px;"> <div>■ Low</div> <div>■ Moderate</div> <div>■ High</div> <div>■ Very High</div> </div>
	Prey Specificity	1.6	2		
	Adult Mobility	2	2.4		
	Dispersal of Early Life Stages	2.1	2		
	Early Life History Survival and Settlement Requirements	2.3	1.3		
	Complexity in Reproductive Strategy	2.1	1.5		
	Spawning Cycle	1.6	2.2		
	Sensitivity to Temperature	1.2	1.8		
	Sensitivity to Ocean Acidification	1.9	1.6		
	Population Growth Rate	1.7	1.6		
	Stock Size/Status	2.8	1.3		
	Other Stressors	2.2	1.2		
	Sensitivity Score		Low		
Exposure variables	Bottom Salinity	1.4	3		
	Bottom Temperature	3	3		
	Current EW	1.3	3		
	Current NS	1.3	3		
	Current Speed	1.2	3		
	Mixed Layer Depth	1	3		
	Ocean Acidification	4	3		
	Precipitation	1	3		
	Productivity	1.4	3		
	Sea Surface Temperature	4	3		
	Surface Chlorophyll	1.5	3		
	Surface Oxygen	4	3		
	Surface Salinity	1.4	3		
	Wind EW	1	3		
	Wind NS	1	3		
	Wind Speed	1.1	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		Moderate			

Threadfin (*Polydactylus sexfilis*)

Overall Climate Vulnerability Rank: **[Moderate]**. (90% certainty from bootstrap analysis).

Climate Exposure: **[Very High]**. Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[Low]**. No sensitivity attributes scored above a 3.0. The highest scores were for Early Life History and Settlement Requirements (2.3) and Stock Size/Status (2.8).

Distributional Vulnerability Rank: **[Moderate]**. Three attributes indicated moderate vulnerability to distribution shift: adult mobility, limited early life stage dispersal (although this is not supported by the prolonged epipelagic juvenile stage of this species), and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may mitigate the propensity of the species to shift distribution.

Data Quality: 75% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

The Pacific Threadfin (*Polydactylus sexfilis*) is ranked as only moderately vulnerable to climate-change effects. It may be susceptible to anthropogenic impacts in watersheds because spawning occurs inshore, larvae and pre-settlement juveniles are epipelagic, and juveniles of this species recruit to river mouths, brackish mangrove estuaries, and shoreline surf habitats [1-8]. The protandric reproductive mode of the Pacific Threadfin makes it vulnerable to fishing pressure and other factors that may increase mortality at larger sizes, thereby decreasing the numbers of females in populations. These additional stresses on the populations may increase vulnerability when added to climate-change effects.

Life History Synopsis:

The Pacific threadfin (*Polydactylus sexfilis*) is also called the sixfinger threadfin [5] and moi in Hawaii. It is found in 17 Spalding et al. [9] provinces throughout the Indo- Pacific region within 34° N–23° S, 50° E–148° W from Madagascar to the Ogasawara Islands of southern Japan, east to Hawai'i and south to the Tuamotu Archipelago [5,10]. *Polydactylus kuru*, considered a separate species until 2001, is now a synonym for *Polydactylus sexfilis* [10]. In a Hawaiian study of juvenile and adult mobility, hatchery-reared fish were recovered on average 11.5 km (SD=9.8 km) from the release site, although some had moved as far away as 42 km [2,11]. Dispersal capability between islands and archipelagos was demonstrated in a study of genetic diversity between O'ahu and Hawai'i islands that found no differences in haplotype structure between the islands and evidence of recent colonization of the archipelago by Pacific threadfin at 14,000–28,000 years ago [12]. Unlike other species of Polynemidae, the Pacific threadfin is usually found on oceanic islands. It is less dependent on estuaries than other species in the family [10]. The species is demersal at depths of 1–50 m [5] and is often found in nearshore habitats with strong wave energy, particularly on shallow sand flats, along high wave-energy rocky shorelines, and at sandy-beach surf habitats [2,5]. It can also be found in turbid water near stream mouths, river mouths, and brackish mangrove estuaries, particularly at or soon after settlement from the pelagic juvenile stage [2,4,13]. In Hawaii, small fishes occur in schools along beaches and in sheltered coves from May through August [4,5]. Adults typically inhabit turbid waters and are usually found in large schools in sandy holes along rocky shores and high energy surf zones at 20–50 m [2]. Local

fishermen in Hawai'i call areas where adult Pacific threadfin congregate "moi holes"; these usually occur in shoreline caves or sandy depressions and sand channels in the surf zone among boulders or reef areas. It is a carnivore, feeding on benthic or demersal crustaceans (predominantly on penaeid and caridean shrimps), fishes, polychaetes, and other benthic invertebrates [1,5,14-16]. Like other polynemids, it is unusual in its reproductive mode by being a protandric hermaphrodite [5]. Male maturity occurs at 20–25 cm fork length (FL) at about one year, and the transition to female maturity occurs at 30–40 cm FL at about three years of age following a hermaphroditic transitional stage beginning at about two years [17-20]. The maximum standard length is at least 46.2 cm and may be 61 cm [2,5,21]. Spawning of Pacific threadfin spawn with a lunar cycle most predictably near the third lunar quarter 8–10 days after the full moon [18]. In captivity, spawning may be less predictable, in any lunar quarter with intervals between spawning series ranging from one week to two months [1]. Spawning occurs inshore in the wild from June through September in Hawaiian waters, but throughout its range and in captivity it can spawn year-round with peak spawning in April–October [1]. In captivity, spawning occurs at 24–30 °C, with continuous spawning at 26–27 °C, and at dissolved oxygen levels above 5 mg/L [13]. Pacific threadfin are batch spawners, producing eggs in captivity once a month for 3–6 days each. The buoyant eggs, 0.75–0.90 mm mean diameter with one oil globule, hatch offshore [13,15,17] approximately 19–20 hours after spawning, at 26–27 °C. Newly hatched larvae are more sensitive to environmental factors than eggs [13]. The pelagic larval duration is about 25–28 days [13,17], but the species has an extended pelagic juvenile stage beginning at about 21 mm and lasting to about 6 cm fork length (FL) that greatly increases dispersal ability [13,17]. Benthic feeding begins at about 13 cm FL [17]. In Hawaiian waters, newly settled young appear in shallow waters in summer and fall with peak recruitment from November to January [11,15,18,19]. Von Bertalanffy growth parameters are not available except for age at first maturity for males, age at sex change, and age at first maturity for females. The average age for recovered hatchery-reared fish was 1.3 years and the oldest was 2.7 years [2], but these are poor indicators of maximum age for the species. The Pacific threadfin is an important species for fisheries in Hawai'i [3,11,17] and elsewhere [5]. It was formerly harvested commercially in Hawaii, but commercial catches have declined steadily since the 1950s and have essentially ceased since 1968. Current regulations are a catch limit of 15 fish per person per day, a minimum allowable size of 7 inch TL (ca. 14.5 cm FL), and a closed season from 1 June to 30 September [2]. The Pacific threadfin is also used in aquaculture and stock enhancement research in Hawai'i where it is raised in ponds and until recently was farmed in offshore cages [4,22-24]. It is also used in nearshore cage aquaculture in the Marshall Islands [25].

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Bigeye scad - *Selar crumenophthalmus*

Overall Vulnerability Rank = Moderate ■

Biological Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 93% of scores ≥ 2

<i>Selar crumenophthalmus</i>		Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.5	2.8	
	Prey Specificity	1.2	3	
	Adult Mobility	1.6	3	
	Dispersal of Early Life Stages	1.2	1.4	
	Early Life History Survival and Settlement Requirements	1.4	1	
	Complexity in Reproductive Strategy	1.2	2	
	Spawning Cycle	1.5	2.8	
	Sensitivity to Temperature	1.2	2.8	
	Sensitivity to Ocean Acidification	1.8	2.6	
	Population Growth Rate	1.2	2.2	
	Stock Size/Status	1.2	2	
	Other Stressors	1.2	2	
	Sensitivity Score		Low	
Exposure variables	Bottom Salinity	1.9	3	
	Bottom Temperature	3.3	3	
	Current EW	1.3	3	
	Current NS	1.3	3	
	Current Speed	1.3	3	
	Mixed Layer Depth	1	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	4	3	
	Surface Chlorophyll	1.5	3	
	Surface Oxygen	3.8	3	
	Surface Salinity	1.6	3	
	Wind EW	1.1	3	
	Wind NS	1.1	3	
	Wind Speed	1.1	3	
	Exposure Score		Very High	
Overall Vulnerability Rank		Moderate		

■ Low
■ Moderate
■ High
■ Very High

Bigeye Scad (*Selar crumenophthalmus*)

Overall Climate Vulnerability Rank: **[Moderate]**. (100% certainty from bootstrap analysis).

Climate Exposure: **[Very High]**. Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[Low]**. No sensitivity attributes scored above a 2.0. The highest scores were for Adult Mobility (1.5) and Ocean Acidification (1.8).

Distributional Vulnerability Rank: **[Very High]**. Three attributes indicated high or very high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and habitat specialization. However, sensitivity to temperature was scored as low.

Data Quality: 93% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

The bigeye scad, *Selar crumenophthalmus* (called “akule” in Hawai’ikilo), are very widespread, found on both continental shelves and oceanic islands circumtropically, from 47° N to 24° S. They are found at depths of 0–170 m, but usually at 2–10 m. Although this species occurs around the world and is called “oceanic,” it is found mainly in shallow inshore waters. There is at least one example that indicates bigeye scad are quite motile and can respond to climate rapidly over long distances. In 2014–2015, the waters were unusually warm in the northeast Pacific. It was then that bigeye scad were found off southern California for the first time [1]. Therefore, *Selar crumenophthalmus* is quite motile and can potentially respond quickly to climate change.

Climate change may affect bigeye scads less than open-ocean and coral-reef fishes. Open-ocean species are being affected by ocean stratification. As the ocean surface warms, the water becomes less dense; therefore, the warm surface water tends to float above the cooler waters rather than mixing. This stratification tends to inhibit transport of O₂ increasing the vertical extent of Oxygen Minimum Zone (OMZ) at the same time the concentration of O₂ within the OMZ has decreased [2]. This has reduced the viable habitat for many species of open ocean fishes, forcing them to shallower waters over the OMZ thereby making them easier to catch [3], leading the catch-per-unit-effort surveys to underestimate the actual effects on the stock. Stratification also inhibits the input of nutrients to the photic zone from below which reduces open-ocean phytoplankton biomass thereby reducing ecosystem productivity by about 1% per year [4]. Although called “oceanic,” scads mainly occur in inshore waters where land masses cause water mixing which decreases stratification.

Scads may be among the relatively few species that benefit from future global changes. The worldwide average of soil erosion from agricultural land is 30 tonnes per hectare per year [5]. Sedimentation is harmful to benthic communities such as coral reefs, but ecosystems based on phytoplankton productivity such as nearshore pelagics can be strengthened by nutrient input.

Life History Synopsis:

Bigeye scad have biological traits that predict it will have more resilience to climate change than most species. Its life cycle is rapid and brief. Bigeye scad reach sexual maturity in 7 months and asymptotic

length in 18 months. It has a very widespread distribution and tolerates a wide range of environmental conditions. It is motile and its requirements are generalized. As testimony to its resilience, it is able to sustain populations under intense predation as well as substantial human exploitation both as food and bait. It is harvested at 200,000 tonnes per year [6]. For at least 52 years (1948 to 2000), the catch of small pelagic fishes stayed relatively constant in the Philippines³. Akule has sustained intense fishery pressure over three decades (1966–1997) in Hawai'i [7] and the catch in the Philippines between 2003 and 2012 was 103,971–114,854 tonnes⁴. Although small pelagics such as the bigeye scad are relatively resilient, precautionary management should be encouraged to sustain the local resources.

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³ www.innri.unuftp.is/pdf/Philippine%20Fishries.pdf

⁴ www.fao.org/fishery/facp/PHL/en

Greater amberjack - *Seriola dumerilii*

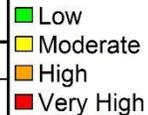
Overall Vulnerability Rank = Moderate ■

Biological Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 86% of scores ≥ 2

<i>Seriola dumerilii</i>		Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.5	2.8	
	Prey Specificity	1.8	2.8	
	Adult Mobility	1.9	2.8	
	Dispersal of Early Life Stages	1.6	1.8	
	Early Life History Survival and Settlement Requirements	2.2	1.4	
	Complexity in Reproductive Strategy	1.6	1.8	
	Spawning Cycle	1.4	2.4	
	Sensitivity to Temperature	1.6	2.6	
	Sensitivity to Ocean Acidification	1.6	2.2	
	Population Growth Rate	1.7	2.4	
	Stock Size/Status	1.8	2.2	
	Other Stressors	2	1.6	
	Sensitivity Score		Low	
Exposure variables	Bottom Salinity	2.1	3	
	Bottom Temperature	3.3	3	
	Current EW	1.3	3	
	Current NS	1.3	3	
	Current Speed	1.3	3	
	Mixed Layer Depth	1	3	
	Ocean Acidification	4	3	
	Precipitation	1	3	
	Productivity	1.4	3	
	Sea Surface Temperature	4	3	
	Surface Chlorophyll	1.5	3	
	Surface Oxygen	3.8	3	
	Surface Salinity	1.6	3	
	Wind EW	1.1	3	
	Wind NS	1.1	3	
	Wind Speed	1.1	3	
	Exposure Score		Very High	
Overall Vulnerability Rank		Moderate		



Greater Amberjack (*Seriola dumerilii*)

Overall Climate Vulnerability Rank: **[Moderate]**. (100% certainty from bootstrap analysis).

Climate Exposure: **[Very High]**. Three exposure factors contributed to this score: Ocean Acidification (4.0), Sea Surface Temperature (4.0), and Ocean Oxygen (4.0). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: **[Low]**. No sensitivity attributes scored above a 3.0. The highest scores were for Adult Mobility (1.9) and Early Life History and Settlement Requirements (2.2).

Distributional Vulnerability Rank: **[High]**. Three attributes indicated high vulnerability to distribution shift: adult mobility, limited early life stage dispersal, and relatively high habitat specialization. However, sensitivity to temperature was scored as low which may mitigate the propensity of the species to shift distribution.

Data Quality: 86% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution:

There has been no explicit study of the impacts of climate change on this species' distribution. Greater amberjack are an exceptionally widely-dispersed tropical and warm temperate species [1]. They feed on a wide variety of fish and invertebrates but are primarily piscivorous as adults [2,3].

Life History Synopsis:

The greater amberjack is primarily (>90%) piscivorous, but cephalopods and crustaceans are a non-trivial portion of the diet of smaller individuals [2,3]. Although frequently benthic-associated, this species is found on multiple habitat types at depths of down to 385 m [1]. Although potentially found at all depths, this species appears most common at depths below around 50 m on both hard and soft bottoms [4]. Maximum reported age is 15 years [5], and this species reaches sexual maturity at around 1.3 years old [6].

This species is capable of quite large-scale movement; a state of Hawai'i tagging program reported several individuals travelling more than 25 miles between recaptures. One individual that was initially captured at St. Rogatien Bank in the Northwestern Hawaiian Islands and was subsequently caught 3.6 years later and 678 miles southward in the main Hawaiian Islands [7].

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